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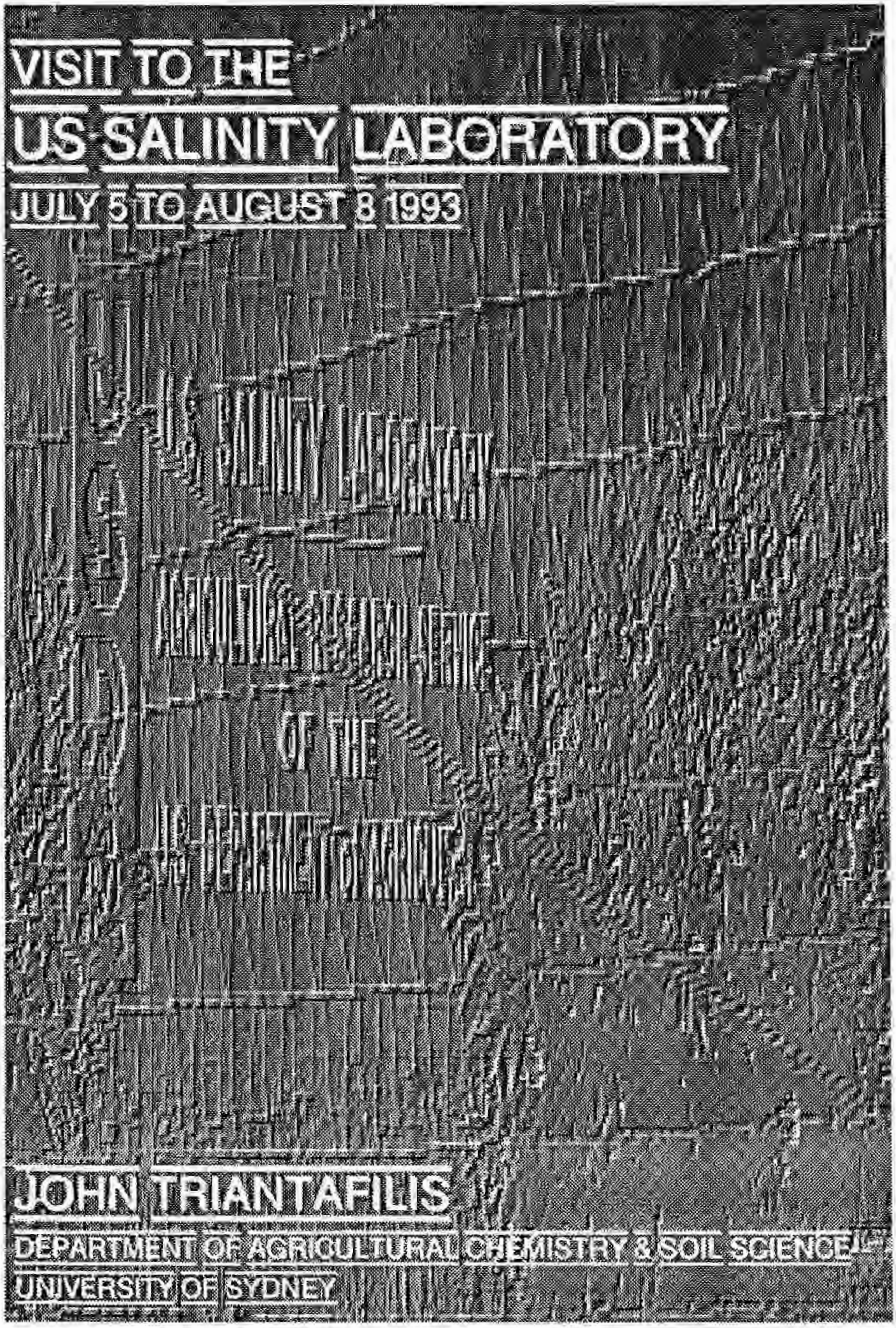
VISIT TO THE US SALINITY LABORATORY

JULY 5 TO AUGUST 8 1993



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CONTENTS

1 INTRODUCTION

The ***Cotton Research and Development Corporation*** Project US05C aims to provide techniques for the rapid assessment of rootzone salinity for cotton growing soil profiles of northern New South Wales and south-eastern Queensland. Many of the techniques currently being investigated in the lower Namoi valley of NSW, where instigated at the United States Salinity Laboratory (*i.e.*, EM38). The laboratory is located in the city of *Riverside in southern California, approximately 60 miles east of downtown Los Angeles.

At this juncture in the research program, where much calibration data has been collected and the surveying of the field site commenced, Alex. McBratney suggested that it would be appropriate to visit the laboratory to observe the research currently being conducted at the laboratory, particularly with respect to the soil salinity assessment program. The visit was completed during the period July 5 to August 8. The following report describes briefly the history, facilities, organization, mission, major research programs and more specifically the laboratory procedures and field methodology of the soil salinity assessment program.

1.1 Salinity and Agriculture

Irrigated agricultural lands account for approximately 15% of the total land culitvated, but produces on a value basis, about a third of the food and fibre of the United States. In the last four decades it has made possible the large increase in worldwide crop production. The practise of irrigation allows the land user to control the supply of water to crops and to utlise areas otherwise favourable to agriculture. Unlike rainfall, surface and groundwaters may contain natural salts such as sodium, calcium, magnesium, pottasium, sulfate and chloride acquired by the water from geological materials with which it has been in contact.

As a consequence of evaporation and transpiration by agricultural crops, the irrigation waters leave salts behind and if allowed to accumulate in the rootzone will ultimately lead to yield reduction by limiting transpiration and/or interfering with plant metabolism. High sodium can also alter the soil structure which leads to impedance of water which can cause water logging, root inpenatrability and can lead to increased soil erosion. Historically, evidence exists that several civilisations which relied heavily on irrigated agriculture, eventually failed because of salinity and water logging problems. It is estimated that potential soil salinisation in irrigated lands around the world could be at least half the total area. Therefore, salinity laboratories like the United States Salinity Laboratory and others are required to protect our greatest natural assets of soil, water and other natural resources.

1.2 History of the United States Salinity Laboratory

In the late 1920's, the Rubideux laboratory was established to conduct water qualtiy research with special emphasis on boron toxicity to plants particularly citrus. In 1935, the United States Department of Agriculture (USDA) and the directors of the Agriculutral Experiment Stations of 11 Western States made the decision to create a laboratory to conduct research on the control of salinity in soil and water for the success and sustainability of irrigated agriculture. In 1937 the United States Regional Salinity Laboratory was established on the grounds of the Rubideux laboratory. Ten years later these two laboratories were combined. With the increase in irrigated agriculture, particularly into semi-arid and arid areas of many of the midwestern states, the number of cooperating Agricultural Experiment Stations was increased to include seven additional midwestern states. The name of the laboratory was changed to its current name the United States Salinity Laboratory (USSL), now administered by the Agricultural Research Service (ARS) of the USDA.

* United States Salinity Laboratory, 4500 Glenwood Drive, Riverside, California 92501, USA

1.3 Facilities

The U. S. Salinity Laboratory occupies seven buildings on nearly 10 acres, located approximately 1 mile from the central Riverside Buisness District, on the footslope of Mt Rubideux (Figure 1). In addition to 11 laboratories, there are two large green houses, a rhizotron, controlled environment chambers, lysimeters, plant culture beds, large outdoor plots, and constant temperature rooms. Most of the research is conducted at the Riverside laboratories, but studies requiring field investigations are undertaken in many of the surrounding agricultural areas including in California the San Joaquin valley to the north and Imperial valley in the south, in Arizona the Wellton-Mohawk Project and in Colorado, the Grand valley area. Due to the age of the present facility and its location a more modern and well positioned facility is currently under construction at the University of California, Riverside campus, at an estimated cost of approximately $US 14 million. Occupation is expected to be complete in mid-1994.

1.4 Organization

The laboratory program involves the combined efforts of four inter-related research management units which are overseen by the Director. The current director is Dr J. D. Rhoades who is also the research leader of the Soil Salinity Assessment and Soil and Water Chemistry unit. The other three units include the Plant Physiology and Genetics, Soil Physics and Solute Transport Modelling, and Pesticide Processes and Modelling unit located on the University of California Riverside campus lead by Drs M. Shannon, M. Th. van Genuchten and W. Spence, respectively. Total staff of the laboratory is approximately 50 of which 18 (PhD level) research scientists are employed. Each unit consists of 3-5 research scientisits supported by technicians and part-time student assistants. Individual research comprises a large portion of the work, but larger projects and other multi-disciplinary studies involve team co-operation by members of all units.

1.5 Mission

The USSL is a United States Department of Agriculture national subject matter laboratory administered by the ARS which is charged with: a) conducting research needed to produce new knowledge and technology required to maintain food and agriculture supplies; b) perform basic research needed to meet ARS mission; c) soil and water conservation; d) maintain environmental quality.

The main objectives of the USSL is to study the basic principles of crop production under

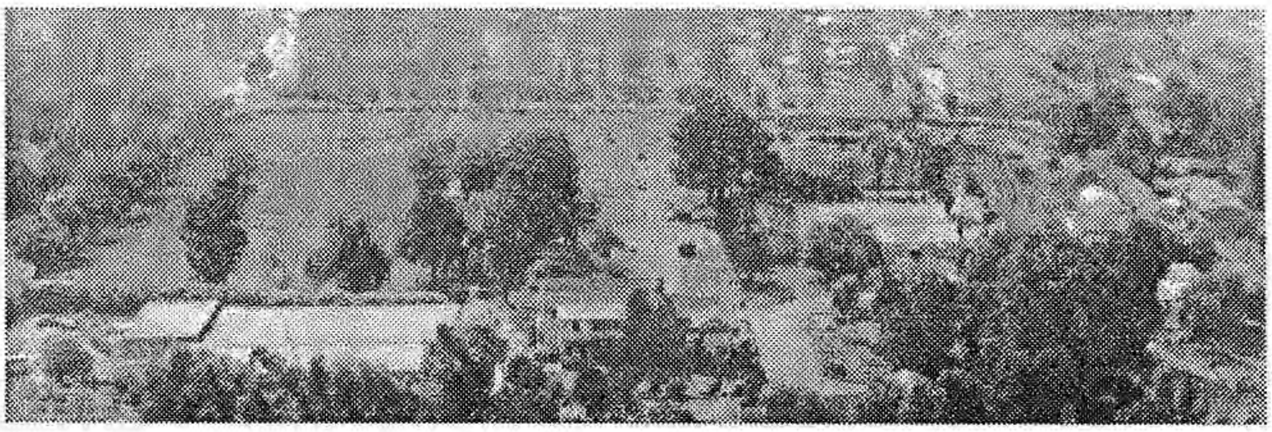

Figure 1. Grounds of the United States Salinity Laboratory.

conditions where excess natural soluble salts exist. This involves work on the study of salinity aspects of irrigation, drainage, soil management, water quality, soil chemistry and plant physiology. In studying these issues the laboratory aims to help bring solutions to: a) the problems of crop production on salt affected lands; b) sustaining irrigated agriculture, and; c) soil degradation and degradation of associated surface- and ground-waters and other environmental pollution.

The research program is designed to investigate: a) the characteristics of salt-affected soil in relation to their productivity; b) the management of salt affected soil; c) salt response and tolerance of economic plants; d) the suitability of water for irrigation and; e) the effect of irrigation practices on ground-water and stream water quality. More specifically, the research programs are designed to: a) elucidate and quantify the relevant chemical, physical and biological processess operative in salt affected soil, to predict their effects on the productivity of soil/water/plant management, to develop control practices to enhance crop production and quality, conserve soil and water resources, protect environmental quality and sustain irrigated agriculture; b) develop computer models and expert systems for prediction and management of water movement, salts and potentially toxic chemicals (including pesticides) in the root and vadose zones of salt affected agricultural soil; c) evaluate the salt tolerances of plant species and develop an understanding of the interactive effects of salinity and relevant environmental factors on plants, elucidate the biochemical, physiological and morphological mechanisms of salt tolerance and salt injury and develop bases for genetic increases in salt tolerance, and; d) develop and test models which extrapolate laboratory data to field situations, with respect to pesticide volatilization and pesticide loadings from agricultural fields to surface and ground waters.

The laboratory strives to contribute to the effective and conservative use of the world's natural resources in crop production, while minimizing the adverse effects of irrigated agriculture on the associated environment and natural ecosystems.

1.6 Publications

Between 1939 and 1960 some 300 research papers were published by Salinity laboratory scientists in international journals and other reports. In 1954, USDA Handbook No. 60, Diagnosis and Improvement of Saline and Alkali Soils was published. This book has become a highly valued source of information to agronomists, soil scientists and farmers in the United States and many other countries. Since this time many other reports and papers have also been published. A publication list of approximately 1200 articles is available from the laboratory upon request.

2 MAJOR RESEARCH PROGRAMS

As mentioned previously, four inter-related research programmes comprise the USSL. Briefly the major research programmes of each of these units are discussed in the following section.

2.1 Salinity Assessment and Soil and Water Chemistry

The salinity assessment and soil and water chemistry unit is concerned primarilly with research on salinity assessment methodology and the kinetics of CO_2 movement through the soil.

2.1.1 Soil salinity assessment
Research Leader: Dr J. D. Rhoades

The primary field of research is focused on establishing methods for the rapid measurement of field soil salinity, diagnosis and reclamation of salt-affected lands, the management of salt-affected soil and the use of saline water (including drainage water) for irrigation. Modern field instrumentation and laboratory and field methods have been pioneered within this group, including the development of Wenner array devices, the EM38 and four-electrode probe for field application. Other work involves the use of GIS to delineate areas with similar propensities for the development of soil salinity on irrigated arid-zone soil. The mapping strategy aims to provide efficient and accurate means of organizing, compiling, analyzing and displaying complex interrelated data bases that are associated with soil salinisation (Corwin *et al.*, 1988). The research conducted within this group has benefit in the control of soil and water salinity as needed to sustain irrigated agriculture and minimising the offsite pollutional consequences of irrigation.

2.1.2 Soil chemistry
Research Leader: Dr D. L. Suarez

Research interests and current activities include modelling CO_2 distribution and fluxes in the soil, modelling major ion chemistry in the unsaturated zone, using kinetic expressions under transient water flow, Se and B solution/solid tranformations, soil mineral weathering and precipitation reactions in arid land soil, and impacts of irrigated agriculture on groundwater quality.

2.2 Plant Physiology and Genetics

The plant physiology and genetics unit is concerned with collection of empirical data for crop growth modelling.

Research Leader: Dr E. V. Mass

Research is investigating the effects of salt stress on the development of the wheat plant from germination to maturity. Detailed growth analysis data are collected to develop a mechanistic computer model called SWHEAT, that simulates the growth and development of wheat in response to salt and other environmental stresses. SWHEAT is temperature driven, materials balance model that simulates plant growth by incorporating atmospheric CO_2 through photosynthesis into dry matter and responds to nitrogen and water stress.

It is envisaged that a wheat growth model that accurately responds to changes in climate, soil salinity, water stress, and anticipated increases in CO_2 concentrations will be beneficial in optimizing the use of marginal soil and water resources, predicting crop responses to soil salinity and to increasing atmospheric CO_2 concentrations, improving our ability to identify and influence the plant processes that are most sensitive to changing environmental conditions.

2.3 Soil Physics and Solute Transport Modelling

The soil physics unit is primarily concerned with the dynamics of water and salts in the soil rootzone and vadose zone.

2.3.1 Soil physics and solute transport modelling
Research Leader: Dr M. Th. van Genuchten

The soil physics unit is concerned with developing water quality models and expert systems for evaluating, monitoring and managing the movement of water, salt and potentially toxic chemicals in the root and vadose zones of salt affected agricultural lands. The primary objectives of the program are: 1) to evaluate the impact of irrigated agriculture on soil and groundwater quality using integrated, unsaturated water-flow and single ion transport models and associated expert systems; 2) to develop multicomponent physico-chemical transport models for the reclamation of saline soil; 3) to evaluate and quantify the effects of preferential flow and soil spatial variability on chemical transport in the soil and through the underlying unsaturated zone and 4) to develop improved methods and techniques for measuring unsaturated water flow and solute transport processes and related soil properties.

2.3.2 Soil physics
Research Leader: Dr F. N. Dalton

Research includes the development, through theoretical and experimental studies, of the fundamental knowledge of transport processes and mechanisms in the soil-plant-air continuum which contribute to efficient management of soil and water resources in a saline environment. Impediments for analytical and numerical solutions of the convective-dispersive equation describing water and salt transport in the rootzone are appropriate boundary conditions at the plant root interface and an adequate description of plant root distributions. In this regard, research is concerned with the conceptual and physical modelling of the soil-water, plant-root interface as it relates to root water extractions, nutrient uptake and yield. Much of this research is supported with coordinated development of instrumentation (including Time-Domain Reflectometry) from critical measurements of soil and plant water energies.

2.4 Pesticide Processes and Modelling

The pesticide processses and modelling unit, located on the campus of the University of California Riverside, is primarily concerned with the sorption, degradation and volatilization of pesticides. Data from field and laboratory experiments are used for modelling purposes for prediction and statistical interpretation. Much of the work is of a similar nature to the soil physics unit.

2.4.1 Pesticide processes
Research Leader: Dr W. F. Spencer

Research is concerned with determining processes and parameters influencing the transport and fate of pesticides and related organic chemicals in agricultural soil and water systems and developing models to predict the transport of pesticides in and through the root and vadose zones of agricultural soil. At present work is proceeding on the development and improvement for measuring and predicting pesticide volatilization under field conditions and on processes near the soil surface which affect volatilization of pesticides and their loss in surface irrigation runoff water.

2.4.2 Pesticide modelling
Research Leader: Dr S. R. Yates

Characterising the transport of pesticides and other harmful substances in the environment and to develop descriptions of the important processes affecting the movement in the subsurface, through the soil surface boundary layer and in the atmosphere are the two areas of interest in this research program. Research involves the development of mathematical models for the transport of water, energy and solutes to the equations governing the solute behaviour can be obtained either analytically or numerically. Research also involves the development of experimental techniques to allow the determination of the pesticides concentration and flux in the atmosphere near agricultural fields. Since the spatial variability of soil physical properties are of the utmost importance in determining the transoprt processes, there is ongoing research in this area (*i.e.*, geostatistics and stochastic modelling).

3 SOIL-SALINITY ASSESSMENT PROGRAM

The visit to the USSL was primarily concerned with meeting Dr Rhoades who has spent most of his research time pioneering various laboratory methods and field techniques for rapid soil salinity assessment. Much of the time spent at the laboratory was used to study the theory and the application of the laboratory methods, particularly the instrumentation, and observe some of the field instruments and techniques. The following section chronicles these observations with some of the theory of operation of many of the

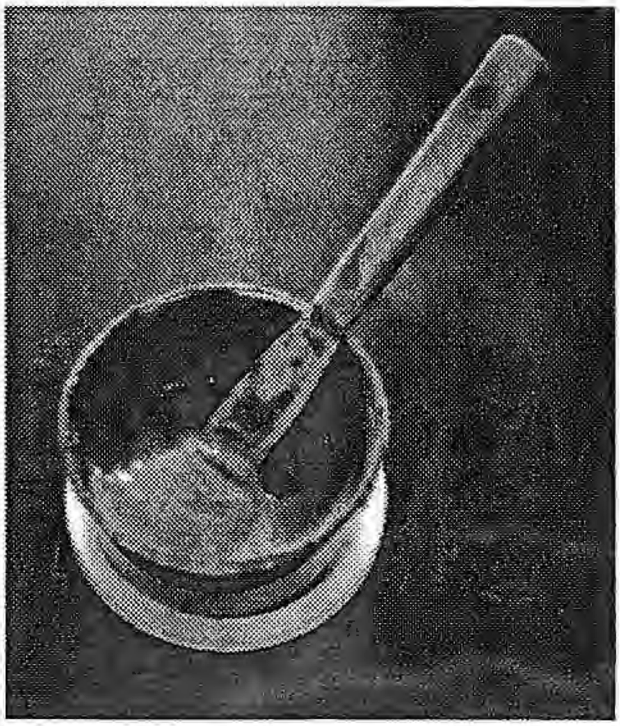

Figure 2. Saturated soil paste extract.

laboratory techniques and field instruments briefly reviewed.

3.1 Laboratory methods

Various laboratory methods exist for evaluating the salt content of soil. These range from large soil-water ratio extracts, such as $EC_{1:5}$ and $EC_{1:2}$ (*i.e.*, 1 part soil to 5 and 2 parts water, respectively) to saturated extracts, such as EC_e (*i.e.*, which closely resembles soil field capacity). Each has advantages and disadvantages. The large soil-water ratio extracts are relatively quick and easy methods for determination of salt content, however, they are likely to provide data on the total salt content of the sample rather than the salt which may be available to the plant.

EC_e or the saturated paste extract, is a time-consuming procedure, requiring the addition of water to the soil while stirring until nearly saturated. The mixture is then allowed to stand for several hours to permit the soil to imbibe the water to achieve a uniformly saturated soil-water paste. The paste, at saturation should glisten as it reflects light (Figure 2), flows slightly when the container is tipped, slides freely and cleanly off the spatula and consolidates easily by tapping or jarring the container. Typically, the mixture is then allowed to stand overnight prior to extraction using a vacuum. The extract is then used to determine the EC_e which gives a better estimate of soil salinity.

Rather than complete the extraction step, the USSL developed a technique in which the electrical conductivity of the saturated paste is determined, (*i.e.*, EC_p). The EC_p can be determined using an instrument similar to that illustrated in Figure 3. The device operates similarly to a normal conductivity meter, requiring no conversion, providing a temperature compensated EC_p. The instrument due to its portability makes it an ideal field instrument for rapid salinity appraisal. The value obtained as well as the saturation percentage (SP), where SP is the gravimetric moisture content (θ_{gSP}) of the

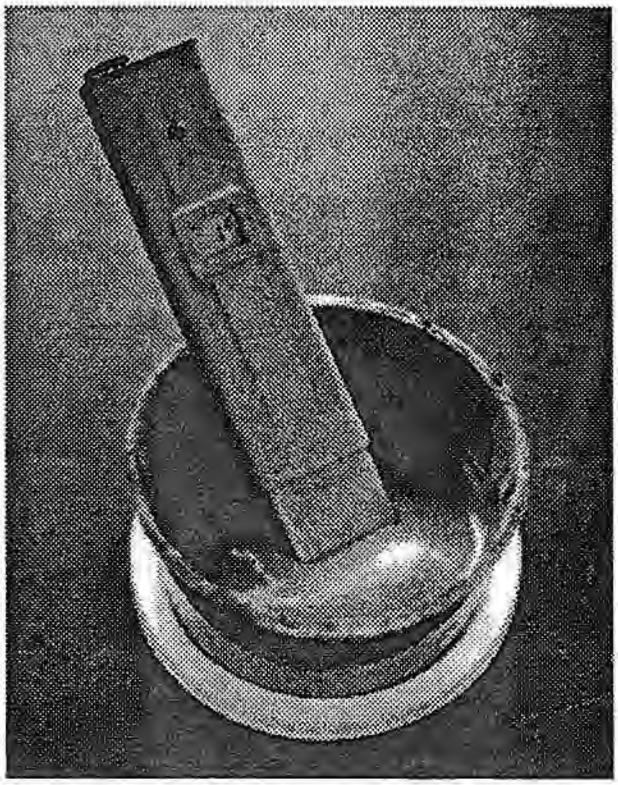

Figure 3. Determination of EC_p using Dissolved Solids Tester.

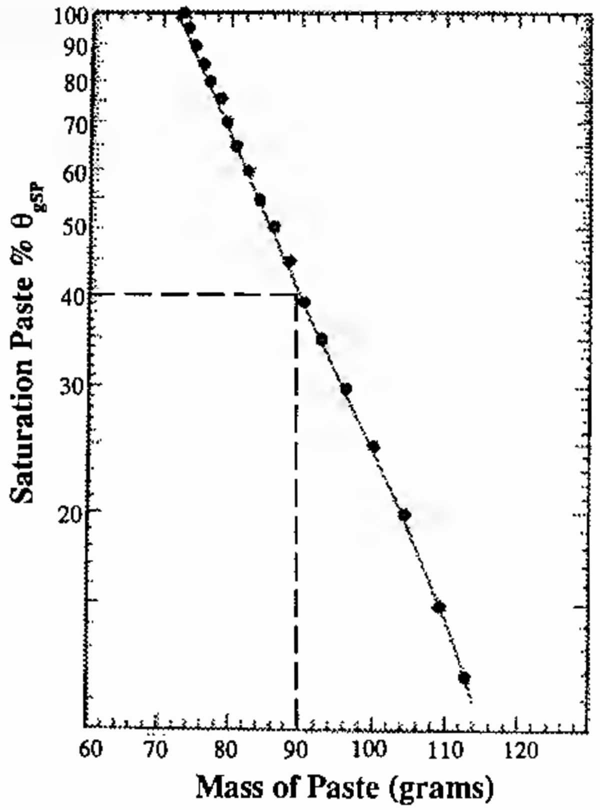

Figure 4. Theoretical relation between θ_{gSP} and mass (in grams) of 50 cm^3 of saturated paste, assuming a particle density of 2.65 Mg/m^3. (After Rhoades *et al.*, 1989).

saturated soil paste, which can then be used to estimate the EC_e. The value obtained for the paste in Figure 3 was 0.15 S/m. The θ_{gSP} of the saturated soil paste is determined simply from the weight of a paste filled cup of known volume from Figure 4 (Rhoades et al., 1989). Usually a volume of 50 cm^3 is weighed. The paste mass of the above example was 90 grams. Therefore the θ_{gSP} of the soil paste is approximately 40. Once the θ_{gSP} and EC_p are known, the EC_e can then be determined using Figure 5, which in our example provides us with a value of 0.43 S/m, a value which indicates that this loamy sand has levels of salinity which will affect some salt-sensitive plant species. The method was designed to be suitable for laborotory and field applications, since the equipment is inexpensive, simple, portable and more rugged than the equipment required to determine EC_e.

3.2 Field sensors for measuring bulk soil electrical conductivity

Physical soil sampling and laboratory analysis provides precise point information data. The precision gained however, is at a cost to field scale salinity assessment. Three types of field salinity assessment sensors currently exist that are capable of determining the bulk soil electrical conductivity at the field scale. These instruments can be used in a rapid reconaissance mode to

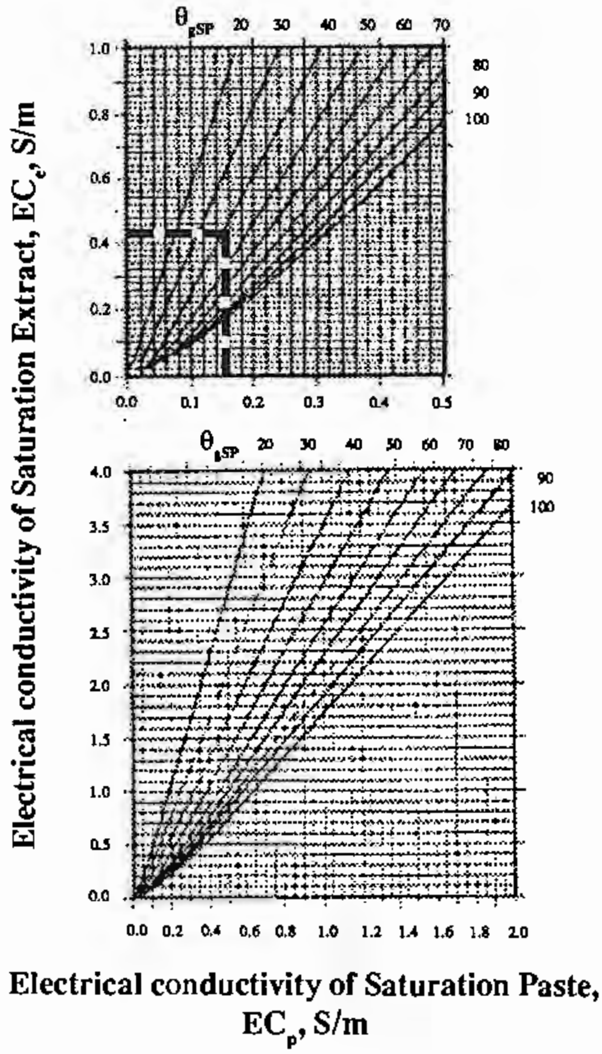

Figure 5. Relation between electrical conductivity of saturated soil paste (EC_p), electrical conductivity of a saturation extract (EC_e), and saturation percentage (θ_{gSP}), for representative arid-land soil (after Rhoades *et al.*, 1989).

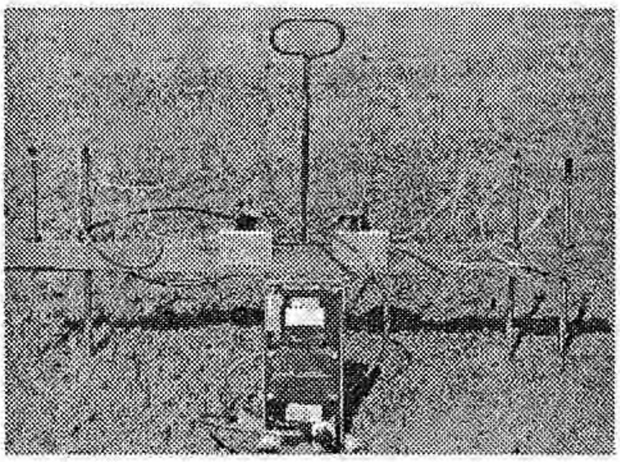

Figure 6. A fixed array four-electrode device with commercial generator/meter.

delineate areas where more detailed and precise laboratory data is required.

3.2.1 Electrical methods

The term 'electrical methods' is usually reserved for instruments where electrodes are physically inserted into the ground to measure the electrical field. The physical property of interest is resistivity. Two such instruments have been tested and developed at the USSL and are field proven and commercially available. The first, is a portable four-electrode sensor (*i.e.*, Wenner Array). A commercially available hand-held unit designed specifically for soil salinity appraisal is illustrated in Figure 6. The fixed array unit, saves time inserting each probe and can be improved upon by the use of a tractor mounted system (Figure 7). Data can be collected rapidly on the salinity status on a field scale with spatial information gathered simultaneously by the use of GPS technology.

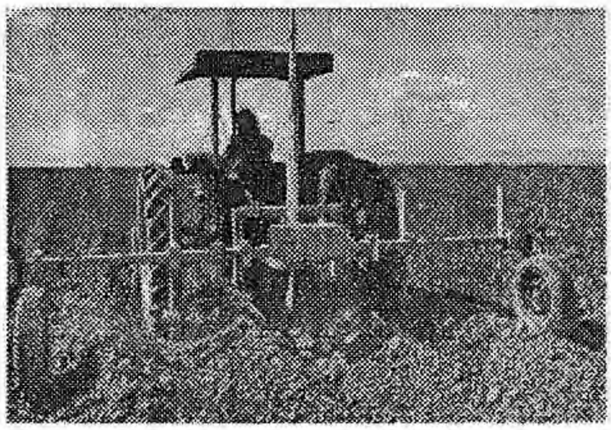

Figure 7. A fixed array four-electrode device with commercial generator/meter.

The surface positioned instruments mentioned above provide the surveyor with data on the bulk soil electrical conductivity, EC_a. For determination of the distribution of conductivity throughout the profile the distance between the surface positioned electrodes can be altered or a four-electrode soil-salinity probe, in which the electrodes are incorporated into a probe, can be utilised for small soil volume measurements (Rhoades and van Schilfgaarde, 1979).

The instrument was designed on a spacing of 2.6 cm (centre to centre) between the electrode pairs, chosen so that soil salinity could be assessed within about 15-cm depth increments, while measuring EC_a in a soil volume of about 90 cm^3. The probe can be inserted into the soil via a previously drilled hole and is tapered (1°) toward the tip for ease of insertion and to ensure that there is firm contact on all four electrodes (Figure 8). The soil salinity probe operates on the same

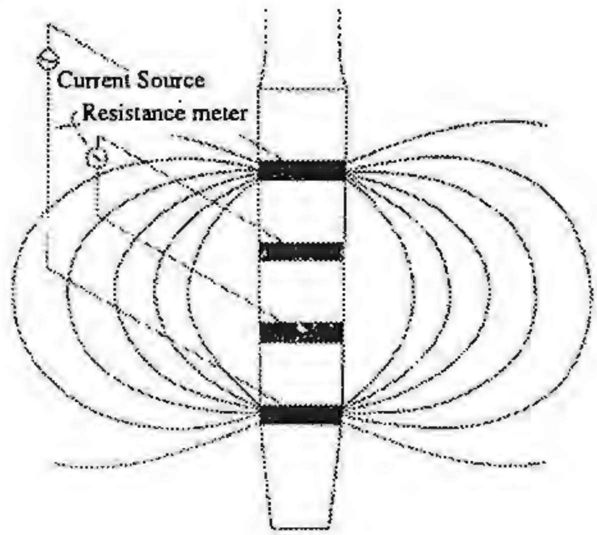

Figure 8. Schematic diagram illustrating the principle of operationof the soil-salinity probe.

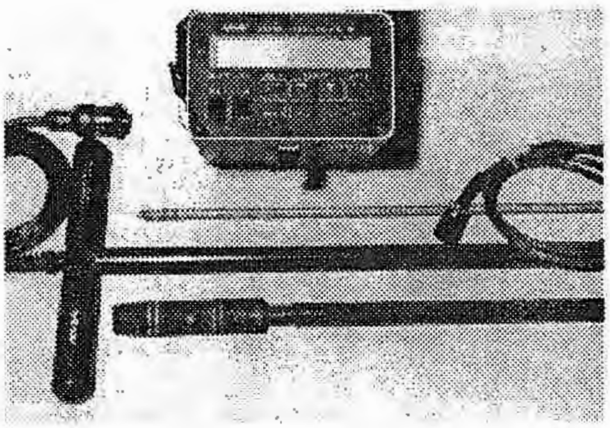

Figure 9. Two commercially available four electrode soil conductivity probes (small and standard) and generator meter/data logger.

principle as the array technique but on a smaller scale, measuring soil conductivity at a discrete depth. Consisting of four brass annular electrodes lying between lucite insulators to form a probe, it is inserted into the soil at depth of interest at which time a current is induced between the two outer elecrodes. The potential drop is measured between the two inner electrodes. The ratio of these two values is recorded as resistance and can be converted into soil electrical conductivity. The volume of measurement is an elliptical volume of soil encircling the probe.

The smaller of the two probes (Figure 9) can be used to determine the salinity of soil directly surrounding an emerging seedling whereas the larger probe can be inserted into the ground at various depths to determine the conductivity profile. These tools provide instantaneous data for management decisions, vis a vis whether further irrigation is required to leach more of the potentially harmful salts present within the rootzone, salts potentially harmful to a germinating seedling. These direct electrical instruments whetether surface orientated or vertically inserted sensors are available commercially and provide data which compliment each other as well as other commercially available instruments, particularly electromagnetic induction devices.

3.2.2 Electromagnetic induction

The term electromagnetic induction is used for methods where induction coils are used to measure the magnetic fields associated with current flow in the earth. The physical property of interest is conductivity. Electromagnetic induction techniques measure the bulk soil electrical conductivity remotely. An electrical current is passed through a transmitter coil at one end of the device which induces eddy current loops in the soil. The magnitude of these loops is directly proportional to the electrical conductivity of the soil in the vicinity of that loop. In a uniformly conductive medium the current loops would be like those presented in Figure 10. Secondary electromagnetic fields are generated from each of these loops, in proportion to the value of current flowing in the loop of which a small fraction is intercepted by the receiver coil. The sum of these signals is amplified forming an output voltage that is related linearly to depth weighted EC_a.

The EM38 device was designed to measure the bulk EC_a to a depth of 2.0m and 1.0 m in the vertical and horizontal modes of operation respectively. The pioneering work conducted on the instrument was carried out at the USSL (Rhoades and Corwin, 1981) and is now

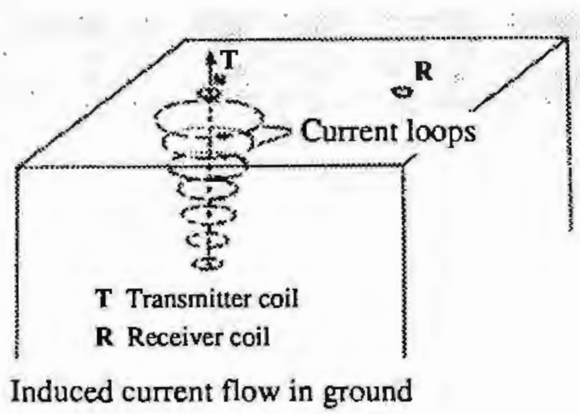

Figure 10. Schematic diagram illustrating the principle of operation of an EM soil conductivity sensor.

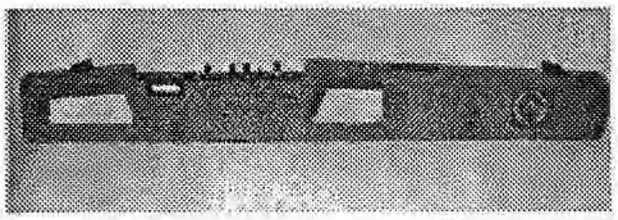

Figure 11. Commercially available digital EM38 soil conductivity sensor.

commercially available (Figure 11) and readily used in field scale salinity assessment. The advantage of the device is that unlike the other methods it does not require insertion into the ground. In terms of mounting this instrument onto a vehicle the advantages of its proximal sensing capabilities is apparent with data collection capabilities improved due to the speed at which the mobile device can travel.

The staff at the USSL in collaboration with agricultural engineers at the United States Cotton Research Station, (Shafter, California) have vehicle mounted much of their equipment. This innovation has consequently allowed them to survey much more land than previously conceivable (Figure 11). The EM38 is housed in the hydraulic arm located at the front of the vehicle and is lowered into position at the desired location. The EM38 can also be rotated between the vertical and horizontal orientations. The elctrode array can also be inserted into the soil hydraulically. The system developed here for the EM38 is similar to that of the mobile four-probe electrode system designed specifically to synchronize the collected data with satellite-based, site-positioning systems. A data logger collects all sampled data.

International interest exists in purchasing the mobile unit, particularly Mexico. The total cost of the vehicle and associated equipment is outlined as follows (all prices $US):

EM38 (rootzone salinity meter)	10 000
- data logger and software	
Texas Spray Rig	9 000
Martek SCT10	3 500
Martek control circuit board	1 000
GPS Pathfinder Basic (x2)	9 000
Fabrication cost	15 000
- hydraulic control system	500
Tow Dolly	1 000
TOTAL	**49 000**

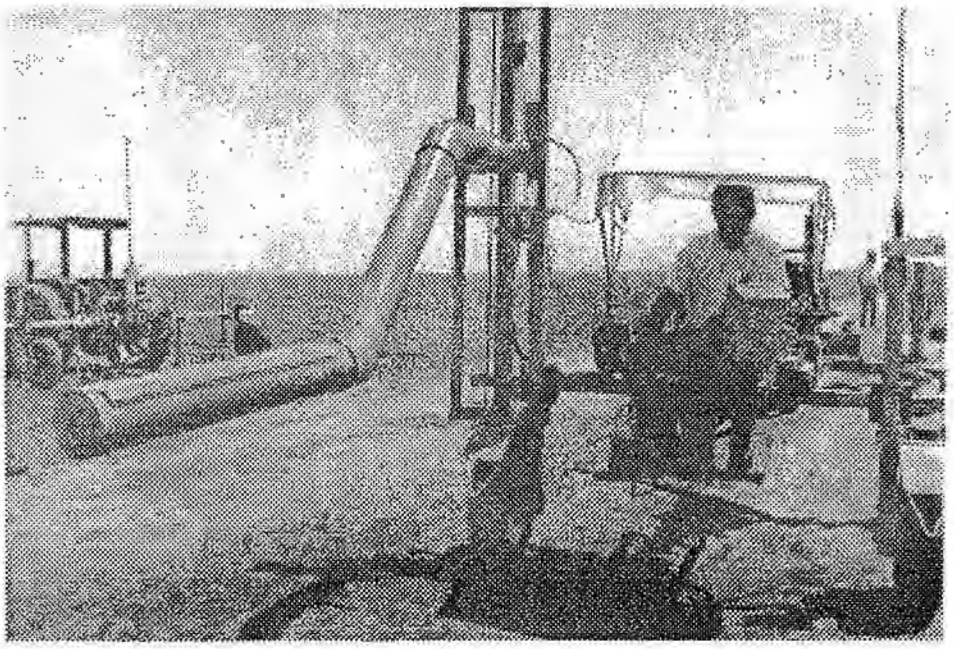

Figure 12. Automated mobile electomagnetic induction vehicle, (After Rhoades, 1992).

This does not include costs for modification and assembly.

3.2.3 Time Domain Reflectometry

The final method of field soil salinity assessment is the relatively new technology of Time-Domain Reflectometry. Time-Domain Reflectometry, or TDR, measures the electrical conductivity and moisture content of soil. TDR is a proven method determining soil moisture content, however its usefulness in determining soil salinity is still in its research stages. If the technique can be refined it offers the potential advantage of determining simultaneously moisture content and electrical conductivity. Work is being carried out at the laboratory to determine its practical application in salinity assessment.

3.3 Salinity Interpretation

The abovementioned techniques all need to be field calibrated to each particular soil type under investigation. This requires soil samples to be taken for analysis in the laboratory. The soil salinity assessment group has a tractor mounted drilling rig for soil sampling. The samples can then be analysed in the USSL mobile laboratory where such calibration data can be analysed. A computer is onboard and allows the data from the mobile EM and four-electrode probe (*i.e.*, Wenner Array) units to be downloaded. Conductivity or EC_a maps as well as calibrated field maps EC_e (pedicted from EC_a using EC_p and θ_{gSP}) can then be produced almost as soon as the survey has been completed and areas delineated for further study or remedial action.

4 RECOMMENDATIONS

During the time spent at the USSL it became apparent that a number of laboratory methods and field techniques developed at the laboratory within the soil salinity assessment group could be incorporated into ***CRDC*** Project US05C, within the lower Namoi valley.

<u>Laboratory equipment</u>:

*the Dissolved Solids Tester (Figure 3) should be purchased to assist with the analysis of the soil profiles sampled (*i.e.*, the determination of EC_e from EC_p and θ_{gSP}). The approximate cost is $US 70.

<u>Field equipment</u>:

*to complement currently utilised methods, particularly the EM38, the brand name soil salinity probe should be purchased. This instrument will provide more information on the distribution of electrical conductivity (*i.e.*, soil salinity) in a larger number of soil profiles. The total cost of this device is approximately $US 4 500.

*purchase a digital EM38 and data logger for much more rapid data collection. The model currently used is a early prototype analogue device and will require updating particularly if it is to be mounted onto a vehicle. The approximate cost is $US 10 000.

*investigations should also be initiated into the costs involved in producing a similar mobile unit as developed by the USSL. Such a vehicle should consider mounting additional instrumentation such as the deeper penetrating EM31 and EM34-3 instruments. A conservative estimate would be approximately $A 75 000.

*due to the utility of the EM31 and EM34-3 instruments in estimating the prescence of deeper salt stores and watertables digital instruments and data loggers should also be considered for purchase by the ***CRDC*** and located at Narrabri for use by consultants, agronomists and land users. Approximate cost of these two instruments are $US 15 000 and $US 18 000, respectively.

ACKNOWLEDGMENTS

The time spent at the United States Salinity Laboratory was an invaluable experience scientifically and personally. I wish to acknowledge the financial support of the ***Cotton Research and Development Corporation*** for providing a handsome scholarship including funds for travel which made this trip possible. I also wish to acknowledge the entire staff at the United States Salinity Laboratory for their time in discussing some of their research interests with me, particularly the research staff of the soil salinity assessment program led by Dr. James (Jim) D. Rhoades (salinity assessment and management of saline soil), Scott M. Lesch (statistical analysis of data) and Nahid A. Manteghi (laboratory manager). I would also like to thank Jim Poss for organising field trips and appointments with other research scientists at the laboratory and at the University of California, Riverside campus, Patti Speckman and Karen Padgett for photocopying and providing me with many journal reprints and photocopies of published reports and finally the summer time staff of Brian, Brent, Darlene, Emmie and Kim who all made my visit to the USSL a enjoyable and educational experience.

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